

# **Reduction of Oxygen (O<sub>2</sub>) in Oven or Furnace Exhaust (Flue) Gases For Industrial Heating Equipment and Boilers**



**Prepared for California Energy Commission (CEC)**

**Prepared By:**

**Southern California Gas Company  
(A Sempra Energy Utility)**

**E3M Inc.**

**May 2012**

## ***Disclaimer***

The CEC and its contractor, Southern California Gas Company and subcontractor E3M Inc. has made reasonable efforts to ensure all information is correct. However, neither The CEC's, Southern California Gas Company's or E3M Inc.'s publication nor verbal representations thereof constitutes any statement, recommendation, endorsement, approval or guaranty (either express or implied) of any product or service. Moreover, The CEC, Southern California Gas Company or E3M Inc. shall not be responsible for errors or omissions in this publication, for claims or damages relating to the use thereof, even if it has been advised of the possibility of such damages.

## ***Executive Summary***

This calculator tool can be used to estimate annual energy savings and the associated cost (US dollars) savings, and reductions in CO<sub>2</sub> emissions through reduction of oxygen (O<sub>2</sub>) level (also known as excess air) within the flue gases from burners that supply heat to a furnace, boiler, oven or other type of heating equipment used by industrial facilities. Energy savings estimates apply for cases where the oxygen (O<sub>2</sub>) level of the flue gases is reduced while maintaining safe and efficient combustion conditions within the heating system. A reduction in O<sub>2</sub> level within flue gases represents a reduction in the total mass flow of exhaust gases and a reduction in energy wasted from the heating system. Flue gas O<sub>2</sub> levels can be reduced through reductions in excess combustion air, air leaks in the system, additional make up air, etc.

This calculator estimates the annual expected energy savings in terms of million British thermal units per year (MMBtu/year). It also estimates the energy cost reduction by using the cost of fuel for the industrial application and the operating hours per year. The amount of CO<sub>2</sub> emissions reduced is also estimated using natural gas as the sole fuel source.

The primary objective of this calculator is to identify energy savings potential in industrial heating operations to make a go / no go decision on further detailed engineering and economics analysis. The user is required to give data for several operating parameters that can be measured or estimated from normal operating conditions using available records. All data should be collected at typical or average unit operating conditions.

The calculator's results should be considered preliminary estimates of energy savings potential and a starting point for more detailed technical and economic analysis. The accuracy of the calculator's results is expected to be within  $\pm 5\%$ .

## ***Note to the User of this Calculator Tool***

Use of this tool requires knowledge of combustion and operation of heating systems such as a furnace, oven, heater, boiler, kiln, dryer etc. The user is referred to several training programs and references quoted at the end of his document for further information on the available resources for getting trainings that would provide additional knowledge for the subject matters discussed in this document.

The following terms are used interchangeably in this document. The terms furnace or heating system represent many different types of equipment used by the industry. They include furnaces, boilers, heaters, ovens, kilns etc. The term combustion system is also used to represent fuel firing systems including burners and furnaces as defined above. The term flue gas can be used interchangeably with combustion products and stack gas.

## TABLE OF CONTENTS

Disclaimer .....	ii
Executive Summary .....	ii
Note to the User of this Calculator Tool .....	ii
1. Description of the subject area .....	1
2. Impact of excess air reduction on energy savings and CO <sub>2</sub> emissions .....	2
3. Discussion on the technical approach and the calculations.....	3
4. Burner air-fuel ratio adjustment for excess air control .....	4
5. Energy savings from reducing air infiltration or air leaks .....	4
6. Energy savings through controlling makeup air.....	5
7. Instruction on use of the calculator .....	10
8. References and resources .....	15

## LIST OF EXHIBITS

Exhibit 1: Combustion system diagram.....	4
Exhibit 2: Composition of natural gas used for calculations .....	8
Exhibit 3: Required information for the calculator user .....	11
Exhibit 4: Example of calculator inputs and results .....	12

## 1. Description of the subject area

This work paper describes a calculator tool that will allow a user estimate annual energy (fuel) savings, reductions in CO<sub>2</sub> emissions, and energy cost savings (\$/year) by controlling the air-fuel ratio (and corresponding excess air) entering a heating system (boiler, furnace, oven, heater, kiln etc.) the system from any other source.

The air-to-fuel ratio refers to the proportion of air and fuel present during combustion. The chemically optimal point at which combustion is most efficient is called the stoichiometric air-to-fuel ratio (also referred to 100% theoretical air). In theory, a stoichiometric mixture has just enough oxygen available to completely burn the available fuel. In practice, complete combustion at 100% theoretical air is never quite achieved, due to incomplete mixing of the fuel and the air and requires additional air to complete combustion. Excess air is defined as the air flow in excess of the stoichiometric air-to-fuel ratio. This value is expressed as a percentage of 100% theoretical air, i.e., if the air-to-fuel ratio is 1.1 times the stoichiometric air-to-fuel ratio, the excess air is 10% of theoretical air.

Reducing excess air offers an opportunity to save energy. Operating a heating system with an optimum amount of excess air will minimize heat loss via the flue gases. The flue gas temperature and flue gas oxygen (or carbon dioxide) concentrations are primary indicators of the combustion efficiency (or available heat) of the system. Given complete mixing, a precise or stoichiometric amount of air is required to completely react with a given quantity of fuel. In practice, combustion conditions are never ideal, and additional or “excess” air must be supplied to ensure complete combustion of the fuel. The current level of excess air within the flue gas can be determined from analyzing the flue gas oxygen or carbon dioxide concentrations. Inadequate excess air levels result in unburned hydrocarbons, soot, and carbon monoxide; while too much excess air results in heat loss due to excessive flue gas flow -- thus lowering the overall efficiency. On well-designed natural gas-fired systems, an excess air level of less than 10% is attainable.

The focus of this tool is on the reduction of natural gas consumption for industrial processes by reducing excess air present in the flue gasses. There are three main strategies to reduce excess air:

- **Control of air-fuel ratio to the burners** – This strategy focuses on reducing the excess flow of combustion air to the burner while maintaining the required air-fuel ratio for complete combustion of the fuel.
- **Control or reduce of air leaks** – This strategy involves blocking leaks in the envelope of the furnace, oven, or other process heating system that allows ambient air to be drawn into the system due to a negative pressure within the system.
- **Control of make up air** – This strategy involves increasing the control over the amount of make up air allowed into a heating unit. This strategy only applies for specific systems (certain types of ovens, kilns, etc.).

A brief summary of the important calculation parameters follows:

- **Flue gas temperature** – The temperature of the flue gases exiting the process before and after implementation of the efficiency measure.

- **Oxygen concentration in flue gas** – The percentage of oxygen in the flue gas (measured on a dry basis) before and after implementation of the energy saving measure.
- **Combustion air temperature** – The temperature of the combustion air (which is the air mixed with fuel in the burner) before and after implementation of the efficiency measure.
- **Fuel consumption per hour (MMBtu/hour)** – The average estimated hourly consumption of natural gas (or other type of fuel) by the baseline combustion system (furnace, oven, kiln, etc.). This should be based on a recent 12-month consumption period (MM Btu/year).
- **Number of operating hours (hours/year)** – The number of hours for which the equipment is operated. This cumulative amount of operational hours should be based on a recent 12-month period.
- **Cost of fuel** – The average fuel cost (\$/MM Btu) based on the past history and, if possible, future projected cost based on contacts with the energy supplier.

## **2. Impact of excess air reduction on energy savings and CO<sub>2</sub> emissions**

This calculator allows a user to estimate energy (fuel) savings that can be achieved by reducing and controlling the amount of excess O<sub>2</sub> in the flue gases discharged from a heating system. These fuel savings result in a reduction of CO<sub>2</sub> emissions. The combustion of all commonly used fossil fuels (such as natural gas) results in the formation of CO<sub>2</sub>. The amount of CO<sub>2</sub> emissions reduced is directly proportional to the natural gas reduction of an energy saving measure.

This calculator is designed to give energy savings estimates with the assumption that the industrial process uses natural gas as fuel. The actual savings in fuel consumption and the associated energy costs depend on several operating parameters. Parameters include:

- Average firing rate (fuel used per hour)
- Temperature of exhaust gases leaving the heating unit
- Amount of excess air used for combustion (as represented by presence of oxygen on a dry basis) in the exhaust gases
- Number of operating hours per year
- Average temperature of the combustion air entering the heating system
- Cost of fuel in terms of \$/MMBtu

The energy savings estimates can vary from 5% for low-temperature processes to as high as 20% for high-temperature processes by controlling the air-fuel ratio at the burner. However, it should be noted that savings can be substantial for measures that reduce or eliminate air leaks into the heating system and measures that control the amount of make up air used in processes that require large supplies of air. The exact value of the energy savings at specific values can be estimated using this calculator.

The CO<sub>2</sub> savings are directly related to energy savings. According to U.S. Environmental Protection Agency (EPA) estimates (Reference 5), the combustion of natural gas used in USA produces 116.39 lbs. of CO<sub>2</sub> per MM Btu heat input. For convenience, most calculations use 117 lbs. CO<sub>2</sub> emission per MM Btu heat input from natural gas. If the natural gas composition is available, it is advisable to carry out detailed combustion calculations to estimate more accurate values for the CO<sub>2</sub> produced by the combustion of natural gas. Reduction in CO<sub>2</sub> emissions is calculated by using the value of reduction in energy (fuel) used for the furnace.

Annual energy cost savings depends on the cost of energy, expressed as US dollars per MM Btu, and the total energy savings estimated using the calculator.

### **3. Discussion on the technical approach and the calculations**

Reducing the amount of excess air within the flue gas will result in energy savings while maintaining the desired heat output or temperature (whichever is desired) within the heating unit. The annual energy savings (MM Btu/year) is the difference between the annual energy use by the baseline system and the annual energy use by the heating system after the implementation excess O<sub>2</sub> control measures. In all cases involving excess air reduction, an essential step is to determine the amount of excess O<sub>2</sub> present in the flue gas during normal operating conditions before and after implementation of the measure. This requires the measurement of the combustion air temperature, flue gas temperature, and oxygen concentration with a flue gas analyzer.

The excess air reduction calculator (tool) can be used to estimate energy savings. This calculator also calculates the combined gas savings resulting from reducing the excess air levels within the stack in addition to preheating the combustion air.

A schematic diagram of the combustion system considered in the excess air calculation is illustrated in Exhibit 1. In this analysis, the excess air includes the combustion air entering through the burner, make up air if used, and air leaks into the system. The flue gas (including combustion products and extra air that has not been used for combustion of the fuel) exits the heating system chamber through the stack. Amount of O<sub>2</sub> in flue gas is an indication of excess air. This tool allows the user to calculate excess air combined from all sources, available heat (or “combustion efficiency”), and potential energy savings.

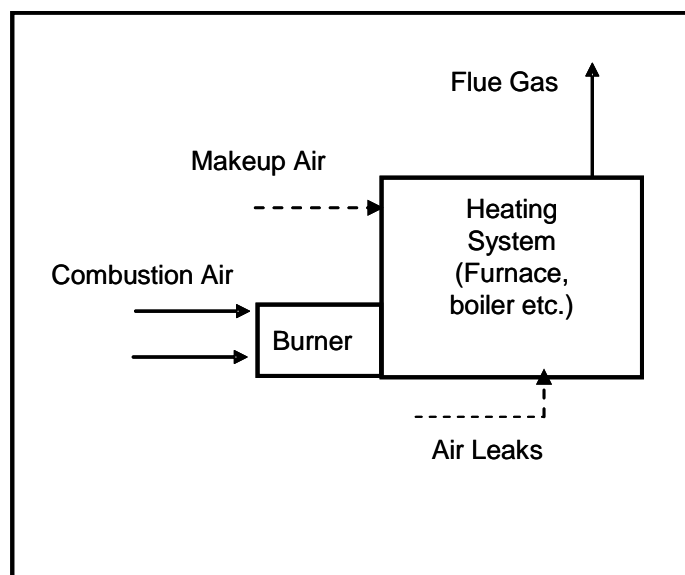


Exhibit 1: Combustion system diagram

In the following section we discuss how to control or reduce excess air for a process heating system and energy savings associated with each source of excess air.

#### **4. Burner air-fuel ratio adjustment for excess air control**

The simplest method to reduce excess air for a burner is to adjust flow of natural gas and/or the combustion air flow rate to the point that CO emissions are near the upper limit acceptable for flue gas emissions while still containing excess O<sub>2</sub> in combustion products. In practice this means controlling air and gas (or other fuel) flow so that the air flow is approximately 10% higher than the stoichiometric amount of air required for the fuel to completely burn. Note that it may not always be possible to adjust a burner to get low value of CO and use 10% excess air for a burner by measuring O<sub>2</sub> content of flue gas, particularly for multi-burner systems, since it is not possible to distinguish combustion products from each burner and the flue gas may contain additional air from other sources. Exact method of the burner air-fuel ratio adjustment depends on the type of burner used and the method of air – flow metering, if any, available for the system. Due to complexity of the adjustments and safety considerations it is strongly advised that the adjustment is made only by the heating system supplier, the burner or combustion system supplier or the experienced and qualified personnel.

#### **5. Energy savings from reducing air infiltration or air leaks**

The pressure in a heating system can be slightly negative (also known as draft) which results from the use of a chimney (or stack) or through the use of an induced draft (ID) fan. This results in ambient air flowing into the system through openings in the system's envelope (inspection ports, doors, feeders, cracks in the walls, bad seals etc.). This air is mixed with combustion products from the burner and increases O<sub>2</sub> content of flue gas. The air also has to be heated to the flue gas temperature before it leaves the system. The heat needed to raise the infiltration air from ambient temperature to the flue gas temperature is provided by the burner. By reducing the



infiltration air flow rate, fuel can be saved at the burner. Several methods are used to reduce or eliminate air leaks. They include installing pressure controls, reducing or eliminating openings, and minimizing usage of doors or other operations that result in air leaks in the system.

## **6. Energy savings through controlling makeup air**

Certain types of ovens or dryers used for processes in which organic solvent or water vapors are formed require makeup air to control the concentration of vapors within the heating system. The required amount of makeup air depends on various vapor characteristics including vapor discharge rate, lower flammability limit, etc. Makeup air mixes with combustion products from the burner and increases O<sub>2</sub> content of flue gases. The makeup air has to be heated to the flue gas temperature before it leaves the system. The heat needed to raise the makeup air temperature from ambient temperature to the flue gas temperature is provided by the fuel used in the burners. Controlling makeup air, will reduce mass of air entering the process and ultimately reduce energy usage.

Several methods are available to control make up air for ovens and dryers that have process or safety requirements. They include:

- i. Using LEL (Lower Explosion Limit) or LFL (Lower Flammability Limit) probes that are used measure LEL levels in order to control makeup air for heating units that produce flammable vapors
- ii. Using a humidity probe to control relative humidity or dew point within exit flue gases

For most heating units, it is necessary to use some amount of make up air and it is not possible to maintain 2% O<sub>2</sub> in flue gases while still operating safely. In such cases it may be possible to adjust the *burners* to operate at 2% O<sub>2</sub> in combustion products; however, the oxygen content of flue gases will be significantly higher than 2% due to make up air requirements. Adjusting the burners to achieve 2% O<sub>2</sub> in the stack while make up air is being supplied to the unit can result in fuel rich operation of the burners and cause unsafe operating conditions. Any equipment supplier should be contacted to determine that sufficient air is being used to meet the process and safety requirements

The energy savings and associated CO<sub>2</sub> emission reduction are calculated for most commonly used hydrocarbon fuels such as natural gas. The savings are calculated for a system in which excess air (represented by O<sub>2</sub>) content in the flue gases is reduced. In these calculations, the system heat demand consists of several areas of heat requirement in a typical heating system (listed in the figure) that must remain constant.

The energy savings are based on changes in the reduction of heat contained within the flue gases and hence change (increase) in “available heat” for the heating system.

The term “available heat” is defined as difference in heat input and the heat content of exhaust gases leaving the furnace system. It is usually expressed as percentage (%) and represents the amount of heat remaining in a furnace as a fraction of the heat input to the furnace.

The following symbols are used in the equations below:

Furnace heat demand (Btu/hr)

Available heat (Btu/hr)

Heat input in the furnace (Btu/hr)

Heat content of exhaust gases leaving the heating system or furnace (Btu/hr)

= Percent available heat

The total heat input is:

The available heat is:

Available heat is expressed as a percentage is used as a good indication of performance of a heating system and it is given as

—

Therefore

\_\_\_\_\_

With the use of reduction in flue gas O<sub>2</sub>, we can consider two different operating conditions. One condition is when the O<sub>2</sub> content of flue gases is high resulting in lower available heat [ ] and another condition when the O<sub>2</sub> content of flue gases is lower resulting in higher available heat [ ]. Correspondingly, the heat input will be higher heat input ( ) or lower heat input ( ) and the available heat percentages will be and

Note that in each case, the furnace heat demand is considered constant at . For each case, the exhaust gas heat content is defined as and respectively.

Hence

\_\_\_\_\_

\_\_\_\_\_

The change in heat input (fuel) in terms of Btu/hr between the two different conditions is

So the change in the heat input, or fuel, in terms of percentages is

, the available heat expressed as a percentage, depends on the following variables:

- Fuel composition
- Exhaust gas temperature
- Combustion air temperature
- Percent oxygen (dry) within the exhaust gases.

Available heat can be calculated by using combustion calculations for a given fuel. For this excess air calculator tool, these calculations use a typical natural gas composition as found in California.

The natural gas composition used for calculations in this tool is given below. Note that the user gives the composition in the column marked “By Volume”. If the values in column “By Volume” do not add up to 100% the program will adjust the percentages under column “Adjusted by Volume” to total to 100% by changing the value of each component proportionately. In most cases the total under column “By Volume” is not equal to 100% due to rounding error.

<b>Fuel Gas Analysis</b> (See note below)		
<b>Gas composition</b>	<b>By volume</b>	<b>Adjusted by volume</b>
<b>CH<sub>4</sub></b>	<b>94.10%</b>	<b>94.241%</b>
<b>C<sub>2</sub>H<sub>6</sub></b>	<b>2.40%</b>	<b>2.404%</b>
<b>N<sub>2</sub> and other inert</b>	<b>1.41%</b>	<b>1.412%</b>
<b>H<sub>2</sub></b>	<b>0.03%</b>	<b>0.030%</b>
<b>C<sub>3</sub>H<sub>8</sub></b>	<b>0.49%</b>	<b>0.491%</b>
<b>C<sub>4</sub>H<sub>10</sub> + C<sub>n</sub>H<sub>2n</sub></b>	<b>0.29%</b>	<b>0.290%</b>
<b>H<sub>2</sub>O</b>	<b>0.00%</b>	<b>0.000%</b>
<b>CO</b>	<b>0.42%</b>	<b>0.421%</b>
<b>CO<sub>2</sub></b>	<b>0.71%</b>	<b>0.711%</b>
<b>SO<sub>2</sub></b>	<b>0.00%</b>	<b>0.000%</b>
<b>O<sub>2</sub></b>	<b>0.00%</b>	<b>0.000%</b>
<b>Total of fuel components</b>	<b>99.85%</b>	<b>100.000%</b>
<b>Difference</b>	<b>0.15%</b>	<b>0.00%</b>
<b>Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C<sub>4</sub>H<sub>10</sub> and all other inert gases are treated as N<sub>2</sub>.</b>		

Exhibit 2: Composition of natural gas used for calculations

For this calculator, the “higher heating value” or “gross heating value” of the fuel is used. The higher or gross heating value for commonly used natural gas with the composition shown in Exhibit 2 is 1,020 Btu per standard cubic foot (scf). The natural gas heating value varies from 970 Btu/scf to as high as 1,200 Btu/scf depending on location and time of year. In many situations 1,000 Btu/scf is considered a good approximation. Note that minor changes in the heating value have very little effect on the savings achieved with changes (usually reduction) in excess air.

It is recognized that natural gas composition may vary somewhat during the year or from location to location. However, a series of calculations shows that the variation in natural gas composition has a very small effect on the available heat as a percentage of the heating value. The changes in available heat are within a narrow range and the error for this value is relatively small (within  $\pm 5\%$ ). Thus, we advise users of this calculator that the accuracy of its estimates will be in the same order of magnitude, i.e.  $\pm 5\%$ . A separate calculator is available to calculate the exact value of available heat when the fuel composition is known or when the natural gas composition is significantly different than the composition shown in Exhibit 2. Further

discussion on available heat and the effect of fuel composition is discussed in References 1 and 2.

The reduction in energy or heat used for a furnace by reducing excess air level can be estimated by calculating changes in available heat temperature. The following equations show the calculation method used for this calculator.

is defined as the annual energy savings of this efficiency measure in Btu/year.

The annual savings amount can be expressed in terms of Btu/year, Therms/year or million Btu/year (MMBtu/year) by using the appropriate equations given below.

The CO<sub>2</sub> savings can be calculated by using the fuel combustion calculations or by using the EPA guidelines for CO<sub>2</sub> generation calculations. Reference 5 gives details of US EPA guidelines.

## **7. Instruction on use of the calculator**

The following list summarizes the user inputs that are required. The user should collect this information before using this calculator tool.

- Company name, plant location and address
- Customer name and contact information
- Heating equipment description (where the energy-saving measure is applied)
- Equipment type (furnace, oven, kiln, heater, boiler)
- Equipment use (e.g., textile drying, aluminum melting, food processing)

Note that some of this information may be optional for the web-based calculators due to users' concerns about privacy.

- Flue gas temperature at the stack where flue gas analysis is taken (°F)
- Oxygen in flue gas (% , dry basis)
- Combustion air temperature (°F)
- Current fuel energy input (MM Btu/hr)
- Fuel (energy cost) in terms of \$ per MMBtu
- Number of operating hours per year

The calculator gives following results:

- Excess air in flue gases (%)
- Available heat for the furnace (%)
- Heat (energy) used per year (MMBtu/year)
- Heat (energy) savings per year (MMBtu/year)
- Energy cost savings per year (\$/year)
- CO<sub>2</sub> savings per year (tons/year)

Note that the CO<sub>2</sub> savings are based on natural gas as the fuel for the heating equipment. A correction factor must be applied if any other fuel is used.

The excess air reduction calculator requires the following input parameters describing the heating process in order to estimate the savings. Exhibit 3 shows the user information screen and Exhibit 4 shows the calculator screen.

The first section requires information about the user, equipment, and process.

Control Air-Fuel Ratio (Reduction of Excess Air [or Oxygen] in Flue Gases)				
1	Company name	ABC Corporation		
2	Plant name or designation	LA Plant		
3	Plant address	12345 Main Street, Gabriel, CA 90878		
4	Contact name	Bob Smith		
5	Contact address	54321 First Street, North Warren, CA 90878		
6	Contact phone number and e-mail	Phone: 916-756-9923	E-mail:	<a href="mailto:b.smith@abccorp.com">b.smith@abccorp.com</a>
7	Date (format mm/date/year)	May 12, 2010		
<b>Heating equipment description (where the energy saving measure is applied)</b>				
8	Equipment type (e.g. furnace, oven, kiln, heater, boiler)	Gas fired furnace		
9	Equipment use (e.g., textile drying, aluminum melting)	Continuous metal heating furnace		
10	Other comments if any	The burners are nozzle mix type with proper equipment to adjust fuel air ratio.		

Exhibit 3: Required information for the calculator user

Line 1 – Name of the company

Line 2 – Name or known designation such as “main plant” or “secondary plant” if applicable

Line 3 – Plant address

Line 4 – Contact name for the plant – This is the individual who is main contact and is responsible for collecting and providing the required information.

Line 5 – Address for the contact person

Line 6 – Contact phone number and e-mail to be used for all future communications

Line 7 – Date when the calculations are carried out.

Line 8 – Type of heating equipment – This is the heating equipment where data is collected and the given energy saving measure is to be applied.

Line 9 – Process or function for which the heating equipment is used – This can be name of the process such as drying, melting, water heating, etc.

Line 10 – Any additional information or comments that can be useful

The second section of the calculator is used for collecting the necessary data and reporting the estimated savings.

As shown in Exhibit 4, there are two columns for the calculator. The “Current” column represents the conditions or data collected as average values for each of the parameters. Details of the data are given below. Data for the “Modified” conditions represents the values for each of the inputs after excess air control measures are implemented. The cells in the calculator are color coded. The white cells are used for data input by the user. The colored (yellow and light blue or green) cells are protected and give results of the calculations. The user is not allowed to change the numbers shown in the colored cells.

In most cases, the only input parameter that will change is combustion air temperature. All other values will be the same as the “Current” conditions.

Control Air-Fuel Ratio or Reduction of Excess Air (or Oxygen) in Flue Gases			
		Current	New
11	Furnace flue gas temperature (°F.)	1,200	1,200
12	Percent O <sub>2</sub> (dry) in flue gases	8.00	3.00
13	% Excess air	55.08	14.92
14	Combustion air temperature (°F.)	70	70
15	Fuel consumption (MM Btu/hr) - Avg. current	20.00	17.32
16	Available Heat (%)	53.8%	62.2%
17	Fuel savings (%)	Base	13.39%
18	No. of operating hours (hours/year)	8000	8000
19	Heat energy used per year (MM Btu/year)	160,000	138,579
20	Heat energy saved (MM Btu/year)	Base	21,421
21	Cost of fuel (\$/Million Btu)	\$ 10.00	\$ 10.00
22	Annual savings (\$/year)	Base	\$ 214,210
23	CO <sub>2</sub> savings (Tons/year)	Base	1,253

Exhibit 4: Example of calculator inputs and results

Line 11 – Furnace flue gas temperature (°F) – Give the flue gas temperature as measured as close to the exit of the furnace as possible. Note that when preheating is done in an extended furnace section or unfired preheat section, this represents flue gas temperature coming out of the furnace and entering the preheat section. Obtain flue gas temperature measurements as close to the exit of the furnace as possible. The flue gas temperature should be taken when the furnace is operating at normal operating conditions from the middle of the stack. Measuring the temperature at the top of the stack or very close to the wall of the discharge duct can give erroneous reading.

Readings taken at non-average production or operating conditions can give unreliable results. Make sure that the flue gases are NOT mixed with cold air before the temperature is measured. Note that in almost all cases the flue gas exit temperature does not change when using load preheating since the furnace zone temperatures are controlled to meet the required process conditions.

Line 12 – Percent oxygen (dry) in flue gases – This value is obtained from a flue gas analysis using commonly available flue gas analyzers. These analyzers give measurements of flue gas components on dry basis in addition to other. The gas analysis sample should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are not mixed with cold air before the temperature is measured. Care should be taken to locate the sampling probe in the middle of the stack or area from where the flue gases are discharged.



- Line 13 – Percent excess air – This is the calculated value of excess air present in the flue gases. It is calculated assuming natural gas is used as the sole fuel. However, this result is considered valid for different compositions of natural gas and for most hydrocarbon fuels.
- Line 14 – Combustion air temperature (°F) – The temperature of combustion air entering the burners. In many cases it is not feasible to obtain exact air temperatures at the burner. A common practice is to use air temperature entering the combustion air blower or ambient temperature as the combustion air temperature if no air preheater is installed. If an air preheater is installed, use the air temperature exiting the recuperator or entering the burner.
- Line 15 – Average current fuel consumption (MM Btu/hr) – This value should be a value based on fuel measurements over a period of time or at “average” operating conditions. It is possible to get this value if the fuel consumption data is available for a certain period of time (monthly, annual etc.) for the furnace being considered. Meter data (if used to calculate the fuel usage) must be corrected for pressure and temperature at the meter and the heat input should be calculated using gross heating value of the fuel. For most commonly used or average quality natural gas a heating value of 1,020 Btu per standard cubic foot (scf) will be a good approximation.
- Line 16 – Available heat (%) – This is calculated value based on the data given above. The calculation uses the “Available Heat” tool developed as part of this tool set and assumes natural gas as fuel. The natural gas composition used for this calculation is same as that given in Exhibit 3 above.
- Line 17 – Fuel savings (%) – This term is calculated using available heat and heat input data for the excess air and combustion air temperature at the current and modified conditions. The equations used for this calculation are discussed in a previous section.
- Line 18 – Number of operating hours (per year) – This value represents annual operating hours of the equipment at the average firing conditions stated above.
- Line 19 – Heat energy used per year (MM Btu/year) – This is calculated using the fuel consumption and the operating hours per year given in Line 15 and Line 18.
- Line 20 – Heat energy saved per year (MM Btu/year) – This is the difference between the heat used per year with the current excess air and heat used per year with the excess air used after implementation of the modified conditions.
- Line 21 – Cost of fuel (\$/MM Btu) – The cost should include all charges related to use of fuel at “the burner tip”. This value can be obtained from the monthly or annual gas bill or by dividing the total annual cost by the annual fuel used.

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

If necessary contact the fuel (natural gas) supplier or distributor for more

information.

Line 22 – Annual savings (\$/year) – This line gives the estimated annual dollar savings resulting from reduced fuel cost.

Line 23 – Reduction in CO<sub>2</sub> emissions (Tons/year) – These savings are calculated based on annual fuel savings, assuming the fuel used is natural gas. The savings are in Short (US) tons, not in Metric tons.

## 8. References and resources

1. *North American Combustion Handbook*, Third Edition, 1986. Published by North American Mfg. Company, Cleveland, OH.
2. *Combustion Technology Manual*, Fifth Edition, 1994. Published by Industrial Heating Equipment Association, Cincinnati, OH.
3. *Improving Process Heating System Performance: A Sourcebook for Industry*, U.S. Department of Energy and Industrial Heating Equipment Association. Available online at [http://www1.eere.energy.gov/industry/bestpractices/pdfs/process\\_heating\\_sourcebook2.pdf](http://www1.eere.energy.gov/industry/bestpractices/pdfs/process_heating_sourcebook2.pdf)
4. *Tip sheets and Technical Briefs*, published by The U.S. Department of Energy. Available online at [http://www1.eere.energy.gov/industry/utilities/steam\\_tools.html](http://www1.eere.energy.gov/industry/utilities/steam_tools.html)
5. *Unit Conversions, Emission Factors and Other Reference Data*, published by the U.S. EPA, November 2004. Available online at <http://www.epa.gov/cpd/pdf/brochure.pdf>
6. Training opportunities for process heating technology
  - The U. S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) Office of Industrial Technologies (ITP) web site. <http://www1.eere.energy.gov/industry/>
  - Sempra Energy – Southern California Gas Company web site [www.socalgas.com](http://www.socalgas.com).  
California Energy Commission web site [www.energy.ca.gov](http://www.energy.ca.gov)